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Operational, Handling and Safety Aspects of the SNQ Target Station

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Summary

Although SNQ accelerator and parts of the target station will be constructed in two stages, the main operation, handling and safety procedures based on the requirements to operate the uranium target in stage II (1100 MeV, 5 mA) should be applied to the target station very similary and nearly uniformly in the two stages. A general view on operation, handling and safety aspects is presented and illustrated by a few selected examples as

- start up and shut down procedures,
- handling of the target wheel in the case of replacement,
- decay heat removal

each under normal and irregular conditions. In the case of failures in the decay heat removal system proof is given for the uranium target of stage II that more than about 7 hours - under pessimistic assumptions - are left to restart the forced cooling, before the cladding (Al) melting temperature is reached. From the more detailed safety analysis currently under investigation it is expected that an emergency cooling system for decay heat removal even in the afore mentioned case is most probably not needed.

1. Introduction

In /1/ it was explained how the target station for the two stages (stage I 350 MeV, stage II 1100 MeV, both 5 mA) will be constructed. It was pointed out, that depending on the tested target materials lead, tungsten and uranium in the first stage the target wheel design can be simplified by omitting tie rods, because of lesser depth of the target material. Additionally for optimum coupling of the lower H_2O-moderator at stage I a somewhat reduced target wheel diameter (a few centimetres) is required. Furthermore a two stage concept for cooling (including shut-down cooling) secures heat removal from the target during operation and shut-down. The cooling system of stage I can also be used for cooling a lead or tungsten target in stage II. Regardless of the mentioned deviations in design the main operation and handling procedures as well as the necessary safety installations for the SNQ target station are uniform during both stages and are designed with respect to the operation of the uranium target of stage II. For the operation of the SNQ-target station with non-uranium targets during stage I significantly lower requirements compared with the final uranium installation are to be expected. Therefore this gives a convenient opportunity to test all installations for operation, handling and safety and to carry out modifications where needed.

2. Operation

2.1 Operation-cycles

The design of the accelerator and target station of SNQ provides for the possibility to run the target station similar to a research reactor. It is anticipated to operate the plant for 9 cycles a year, each of 5 weeks duration. There will be up to 30 days of operation per cycle, with 5 days shut-down time. It is aimed at reaching a total operation time of 6000 hours per year. Additionally there will be one longer shutdown time of the duration of one operation cycle for maintenance, repair and rearrangement work (on experiments too) but mainly for repetition of plant component testing due to licencing requests, which have to be carried out during plant shutdown and which usually take a longer time for preparation. For these reasons there will be a planned operation schedule for about 350 days each year. The remaining time, if needed, will be used in a rather flexible way for special activities, which will either be carried out when the plant is in operation (perhaps at part-load) or during shut-down.

2.2 Start-up, shut-down and normal operation of the target station

The following essential conditions for operation of the target station - shooting with protons at the target - have to be provided for

1. Target wheel in rotation at nominal speed.
2. Target cooling (nominal flow) in operation.
3. Moderator cooling (H_2O and D_2O) on
4. Shield cooling (target block and trolley) on.
5. Shut down cooling and possibly cavern flooding system prepared for start.

Interlocks prohibit, if one of the conditions is missing, the aiming of the proton beam at the target. For this reason the relevant data of each of the conditions are controlled partially in a multiple way (redundant and diverse). For instance, for the first one (target wheel in rotation) the following data are measured:

- rotation speed by two inductive systems
- pressure and flow in both the drive and bearing circuit with additional control of the pumps power consumption.

The target station is started-up by stepwise starting the KLA-H_2O-moderator system.[1.)] At first the part of the circuit for the axial and radial bearings of the target wheel is started. Only when the nominal values of pressure (60 bars radial, 30 bars axial) and flow (4,5 m³/h) are reached in this circuit, the control of the turbine circuit is unlocked for start-up. This circuit sets the target wheel in motion. The circuit is operated at a pressure of 37 bars and a mass flow of maximum 126 m³/h until close to the nominal rotation speed of the wheel (0,5 rotations per second ± 5%). By automatic control the mass flow in the turbine loop will be controlled for reaching and thereafter keeping constant nominal rotation speed. Only then the target cooling loop will be switched on and the cooling flow through the target will be set at 250 m³/h during stage I respectively at 500 m³/h during stage II including the part mass flow of the turbine and bearing circuits. After the start-up of the circuits for the H_2O-and D_2O-moderator as well as for the shielding the central interlock will be unlocked when reaching nominal mass flow in these circuits, so that the proton beam can then be aimed at the target.

During operation all relevant data of the cooling and supply circuits as well as target rotation are automatically monitored. If the speed of the target wheel or mass flow of the target cooling decreases below the fixed limits (about -20%), the proton beam will be stopped by automatic control within a second. In this case injection and high frequency of the accelerator are switched off. Accordingly, a decrease of the values in the moderator circuits (about -30%) sets off automatic warning in the control room, where switch-off of the proton beam can be carried out manually.

Additionally the SNQ-plant is equipped with a fast shut-down system, that automatically switches off the proton beam in less than 10 ms taking into account the total

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[1.)] KLA: Kühlung-cooling, Lagerung-bearing Antrieb-drive (table 5 /1/)

response time. For the target station only the condition "unpermissible high beam losses of the bending magnet" triggers the fast switch. (see Fig. 2 /1/)
As an example in chapter 4 for the cases
- loss of target cooling and
- decrease of target speed

proof is given, that a switch-off of the proton beam in the order of a second is sufficient to limit temperature increases in the materials (target pin) and other structural materials of the wheel to a level, that destruction (melting) can be excluded. If automatic switch-off occurs due to a decrease of the speed of the wheel, the main pumps of the target cooling circuit remain in operation for about 15 minutes before the shut-down pump takes over the water circulation for decay heat removal. However, if loss of target cooling has caused the switch-off, then automatically the shut-down circuit takes over the after-heat removal at once.

3. Handling Concept of SNQ Target Station

3.1 Remotely handled Components

The material tests at present in progress already indicate, that for the components under the highest load in the radiation field of the target station (for instance, beam hole windows, D_2O Moderator tank bottom...) rather long life times (several years) are permissable /2/. This will in future be confirmed in part through extensive irradiation tests in high-capacity accellerators. The design basis at present still is exchangeability of important components - listed up below - of the target station. Additionally the stepwise realisation of the SNQ requires the use of different target wheels (at least lead and/or tungsten and uranium in the first and second stage). For this in the conceptual design exchangeability has to be considered in any case.
The components to be exchanged and therefore remotely to be handled can be classified into three categories:

1. target wheel
   KLA-unit
   H_2O-moderator
   cooled shielding (removable)
2. bending magnet
   neutron beam stop
   connections of the target trolley
   end plate
   pipes/valves of proton beam line
3. D_2O-moderator
   cold source
   beam hole rotating shutter (or parts of it)
   beam hole windows
   (For position and size of these components see fig. 1 and 2 /1/)

The components of categorie 1, especially the target wheel, are of greatest importance for the design of the handling concept of the target station. Therefore, as described in /1/ and the following chapter, they are placed on the target trolley, which can be moved into the operating position in a cavern in the centre of the shielding block of the target station. The IWR[1.)] service cell, immediately connected to the target block therefore serves the purpose of remote handling of the target trolley with the components positioned on it.

The components of categorie 2, aside from faults of their own, only have to be handled, if the target trolley is to be brought into the IWR cell. That means, that the frequency of handling those components is not determined from their design but from the components of the target trolley.

For the components of category 3 like for parts of modern high-flux reactors exchangeability must be provided for in the design. These components are either disassembled or complete size to be replacable by means of shielding containers. If such replacement is necessary, it is advan-

[1)] IWR (Inspektion-inspection, Wartung-maintenance, Reparatur-repair)

tageous, that the components can be transported into the IWR-cell in a short distance and be inspected, overhauled and even to a certain extent be repaired. In this case the for other reasons necessary IWR cell is rather usefull. However, in principle transportation of these components in the above mentioned shielding containers to other Hot Laboratories outside SNQ is conceivable. The design of the IWR-cell takes into consideration size and weight of all components to be handled in it. From the level of radioactivity and surface doserate the uranium target wheel of stage II is the deciding component.
It is antipated to handle the uranium target wheel of stage II first 5 days after shut-down of the SNQ-target station. At this time the decay heat is about 18 KW, the activity about 3 M curies.
Activity inventory and after heat of the other materials (lead/tungsten) are significantly lower, so that handling can already be started one day after shut-down of the target station. The uranium target of stage I can also be handled at this earlier date. In this case the expected activity inventory is lesser than 3 M curies and after-heat below 7 kW. The afore mentioned waiting times will be maintained under all circumstances during the later operation of the SNQ plant. From this follows, that only the targets of stage I and the non-uranium targets of stage II can be handled within the normal shut-down period of each cycle. For the exchange of a uranium target stage II including the waiting time (5 days) a minimum of 7 to 8 days will be needed, a lenght of time that requires special planning (depending on requirements) respectively will have to be planned within the annual long-term plant shut-down.

3.2 IWR Cave Line

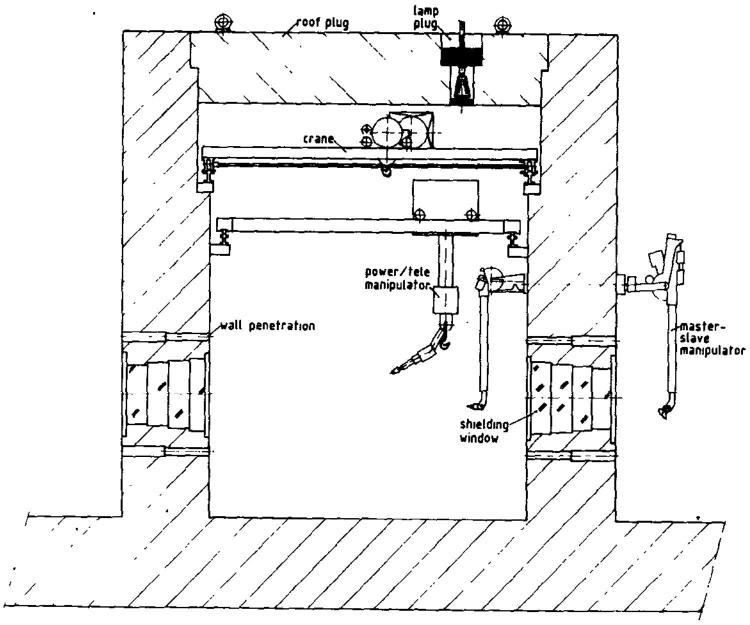
Formerly the Hot Cells necessary for remote handling of target block components were referred to as IWR cell (see /1/ and 3.1). However, because of its actual design as a subdivided line of caves it is now called IWR-cave line.
For the purpose of handling the above mentioned highly activated components the IWR-cave line connected to the target block by the cavern ante-room was designed. (see Fig. 2 /1/). In this cave line all necessary handling can be carried out with the appropriate equipment installed in there. Because of handling reasons and operation sequences the design is a rather narrow cave line of 5 m width with a total lenght of 30 m excluding the ante-room. It is subdivided by shielding doors into three caves

- assembling/disassembling cave adjacent to the cavern ante-room
- workshop cave
- entrance cave

The cave line is separated from the ante-room by another shielding door and from the hall in which it is located by an airtight shielding door. The cave line over its total lenght has shielding windows and extended reach masterslave manipulators on either side. Inside a power manipulator and crane are moved on rails with the crane moving in the higher position close to the cave ceiling. (see Fig. 1) Alternatively the working arm of the power manipulator can be replaced by a telemanipulator.
In order to be able to move the afore mentioned (3.1) components about into the wanted positions a railtrack is installed over the total lenght of the cave line floor and extended through the cavern ante-room to the entrance of the cavern in the target block. Shielding gate locks and shielding plugs on the cave line roof provide for travel of radioactive or heavy components into and out of the cave line. Additionally the entrance cave can be used for the same purpose - especially for new components or materials and waste removal in shielded containers.
For shipment of small-size tools or spares in and out of the caves glove boxes with shielding gates or one-way sluices are provided for. Under floor, with entrance from the workshop cave, a dry storage

bunker for active materials and components and a wet storage bunker for a uranium target are availlable.

FIG. 1: EQUIPMENT FOR HANDLING IN IWR-CAVE-LINE (VERTICAL VIEW)



Several wall penetrations in various positions around the shielding windows supply electricity, gases, water and air to the caves or can be equipped with viewing devices.

Special handling equipment is only transported into the caves when needed.

All walls of the caves have a painted stainless steel liner in order to facilitate decontamination of the caves.

In the cave floor drains are placed.

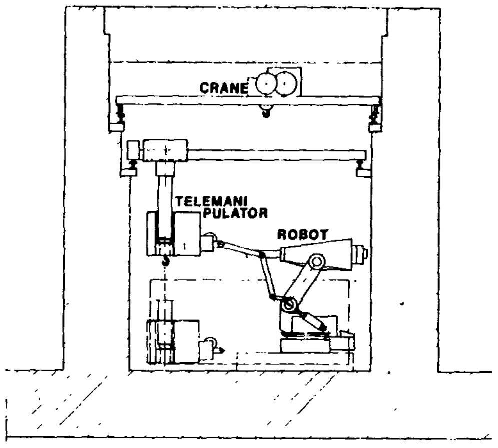
3.3 Handling of the Target Wheel

The target wheel with its drive is fixed on a trolley. When inspection, repair or exchange is required or necessary the trolley will be moved into the assembly cave where the actual handling takes place. Before it is possible to actually remove the target wheel with the trolley from its working position in the target block cavern it is necessary to carry out a number of operations prior to this in the following sequence:

Handling under normal conditions

Special equipment for remote handling in the cavern ante-room comprising crane, telemanipulator, robot plus auxilliary tools, (Fig. 2) viewing equipment and trolley drive are inserted into the IWR caves and moved into their working positions in the ante-room. In combined or successive operations of the handling equipment in a suitable order of steps all connections and fixings are removed and beam stop, bending magnet as well as all other, disassembled parts are brought to a parking position in the front end (workshop

FIG. 2: VERTICAL VIEW OF CAVERN ANTE ROOM



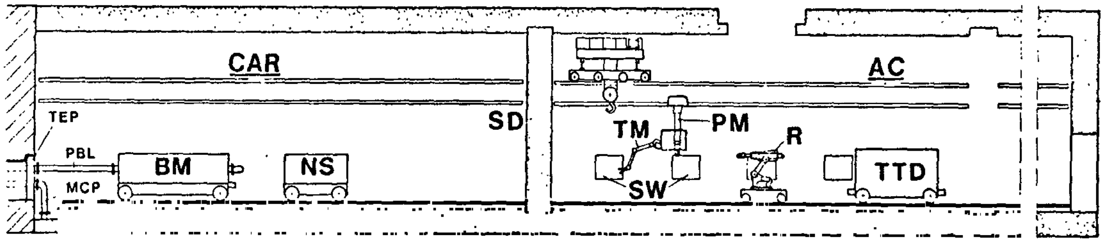


Fig. 3.1 Introduction of Handling Equipment

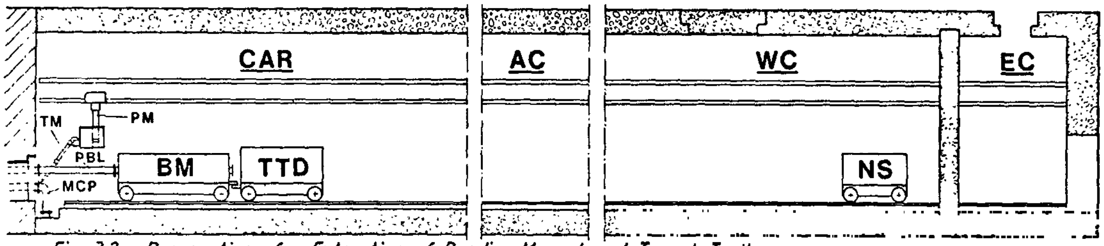


Fig. 3.2 Preparations for Extraction of Bending Magnet and Target Trolley

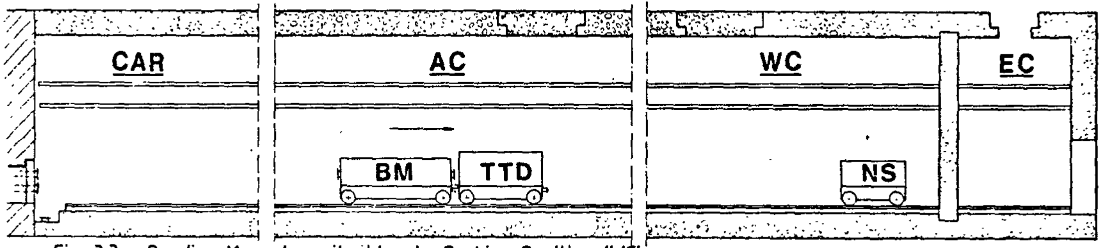


Fig. 3.3 Bending Magnet on its Way to Parking Position (WC)

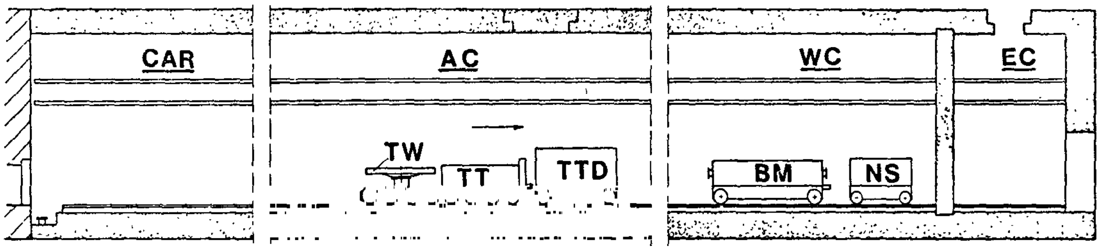


Fig. 3.4 Target Trolley on its Way to Handling Position (AC)

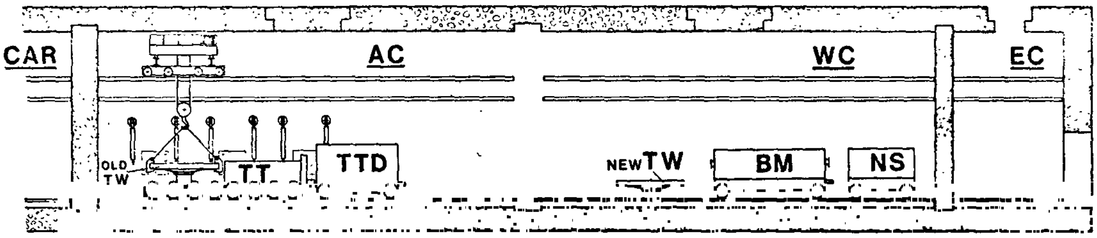


Fig. 3.5 Lifting of the (old) Target Wheel

AC	ASSEMBLING CAVE	SD	SHIELDING DOOR
BM	BENDING MAGNET	SW	SHIELDING WINDOW
CAR	CAVERN ANTE ROOM	TEP	TROLLEY END PLATE
EC	ENTRANCE CAVE	TM	TELEMANIPULATOR
MCP	MAIN COOLING PIPE	TT	TARGET TROLLEY
NS	NEUTRON STOP	TTD	TARGET TROLLEY DRIVE
PBL	PROTON BEAM LINE	TW	TARGET WHEEL
PM	POWER MANIPULATOR	WC	WORKSHOP CAVE
R	ROBOT		

or entrance cave) of the cave line. Finally, again using the above handling equipment, the vacuum seal between trolley end-plate and cavern is removed and removable pieces of the rail track are fixed to brigde the gap between rail track and cavern. Having taken the trolley by means of the drive connected to it into the handling position in the assembly cave the remote handling operations are then carried out in the usual well known ways. If work on the target wheel is finished, all operations for relocation of the target wheel into its working position follow the same pattern of steps in reverse order. A spent target wheel will be disconnected and removed from its drive, fixed into a rack in upright position and stowed away into the wet storage bunker for later examination and/or disposal. Fig. 3 shows the above mentioned handling sequences.

Handling under faulted conditions

The afore handling procedures describe handling under normal conditions. However, if faulted conditions occur, provisions have been made in the following manner. The worst of thinkable faulted conditions is, if, after having disconnected the cooling water pipes from the trolley end plate, the trolley for whatever reason cannot be pulled out of the cavern. In this case a small size flexible water pipe will be connected to the flange of the target cooling pipe providing for the removal of the target after-heat (see also 4.3) and then one can start other appropriate actions, for instance in the case of drive failure the introduction of a 50 ton-winch and drawing trolley and drive by force into the IWR-cave line and only then doing whatever repair is needed by means of the equipment available in the cave-line. A less grave case is, that the trolley is stopped before reaching the handling position in the assembly cave. In this case some cooling is available already from the normal cave ventilation (a total amount of air flow of about 40.000 m^3/h). By means of a movable fan a significant portion of this air flow can be directed onto the target surface.

Thus having secured cooling for the target wheel the following procedures are carried out as explained before.

4. Safety aspects of the SNQ Target station

In stage II of SNQ the uranium target reaches a radioactivity level of 3.10^7Ci, mainly fission products from high energy and fast fission of uranium /3/. The radioactivity generates a decay-heat of half the magnitude of a fission reactor with the same time dependency. Save enclosure is provided for by several barriers in sequence and a reliable after-heat removal like in nuclear reactors. As a longer interruption of target wheel cooling is tolerable from the safety point of view, after heat removal is easier compared with research reactors.

4.1 Multiple enclosure of radiactivity

The arrangement of the activity barriers is shown in principle in fig. 4. The barriers are

- the metallic cladding of the target pins
- the primary circuit and
- the target wheel cavern, the IWR-cave line, the proton beam line and the room for auxilliary plant installations.

During normal operation the cavern is under vacuum maintained by a vacuum system. The vacuum system is equipped with retention units like condenser, filters for air-borne particles and silicagel dryers in order to retain over 99 % of aerosols and water, stemming from leakages of the sliding seal of the target wheel. If necessary, the vacuum system can be shut-off and closed. The cavern is connected to the accelerator by the proton beam line. If the vacuum in the cavern breaks down, this connection is closed by valves.

The IWR-cave line and the room for auxilliary systems, in which the primary loop is housed, are kept under underpressure by ventilation systems during normal operation. If needed, the exchaust channels can be closed. In addition, target block and IWR-cave line are situated in a hall, which is ventilated by a ventilation system too, and is also kept under a little underpressure compared with the atmospheric pressure outside. Thus it has been secured, that no radioactivity is uncontrolled released into the environment.

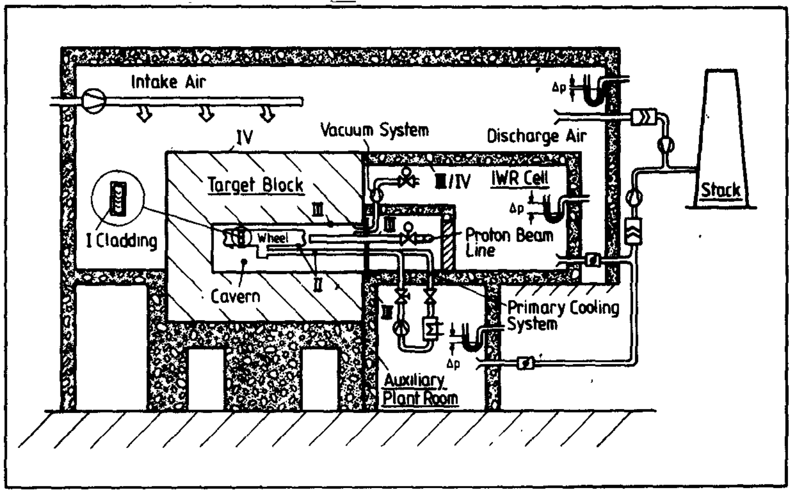


FIG. 4: ARRANGEMENT OF THE ACTIVITY BARRIERS OF SNQ TARGET STATION (SCHEMATIC)

4.2 Decay-heat removal

Generally, decay-heat is removed by the primary and secondary circuits (fig. 5) The turbine loop is not needed for this purpose, and is therefore switched off. After shut-down one of the two shut-down pumps fed by emergency diesels in the case of power failure takes over the circulation of cooling water in the primary loop. The decay-heat is transmitted into the environment by the secondary circuit. The cooling tower ventilators are not needed for this and are therefore switched off. The secondary cooling water is circulated by one of the main pumps. Mostlikely no emergency power supply is required for the secondary pumps, as an interruption of cooling of the secondary loop is tolerable for more than one day. (see fig. 6)

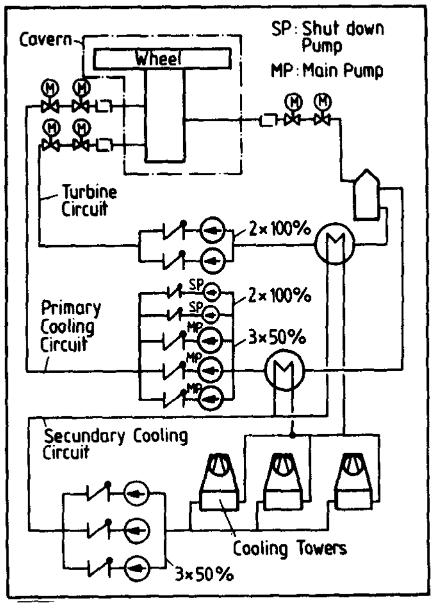


FIG. 5: PRIMARY AND SECONDARY COOLING SYSTEMS OF SNQ TARGET STATION (SCHEMATIC)

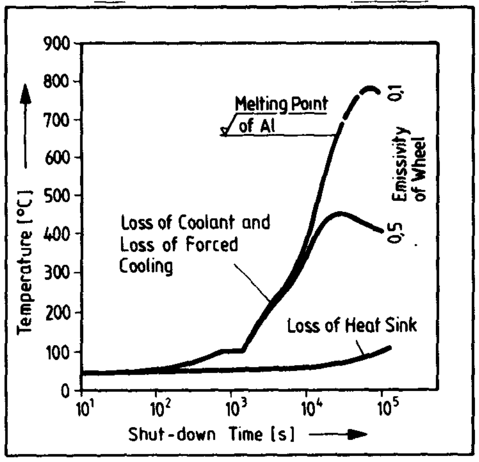


FIG. 6: TIME DEPENDENT MEAN TEMPERATURE OF THE URANIUM TARGET PINS FOR VARIOUS ACCIDENTS

4.3 Decay-heat removal failures

The loss of heat sink in continued operation of primary circulation only leads to a very slow temperature increase in the primary circuit as the lower curve of fig. 6. shows.

For an assumed volume of 20 m^3 of the primary circuit it takes more than one day to heat the water up to the saturation temperature. This time should be sufficient to put secondary circuit back into operation after failure.

In the case of loss of forced cooling the decay-heat is stored in the target wheel and transfered via wheel surface to the cavern and its structure. The expected temperature increase is shown by the upper curve of fig. 6. At first the temperatures raise monotonously up to the saturation temperature. The stagnation of the temperature curve is due to the evaporation of the cooling water trapped between the target pins. The steam is forced into the cooling circuit. After complete evaporation the target pins and the wheel continue to heat up, until the generated heat is transfered from its surface into the cavern and its structures by radiation. With unprepared surfaces of the chosen materials the temperature maximum exceeds the melting temperature of aluminium, which is the chosen material for the wheel and for the canning of the pins. The melting temperature would be reached after about 7 hours at the earliest leaving plenty of time for restarting the forced cooling. Reaching the melting temperature can be excluded, if the emissivity of the heat exchanging surfaces can be improved to 0,5 respectively 0,6. This can be achieved for the target wheel by anodizing the surface.

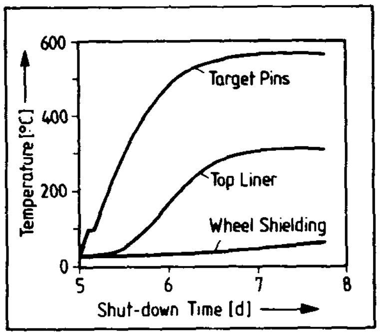


FIG. 7:
TIME DEPENDENT TEMPERATURE OF VARIOUS COMPONENTS IN THE CAVERN IN THE CASE OF LOSS OF COOLING DURING HANDLING 5 DAYS AFTER SHUT-DOWN

Loss of coolant accidents are to be separated into two categories, whether a rupture of the primary circuit occurs inside or outside of the cavern. In the first case the cavern will be flooded, the cooling circuit however is not interrupted by this, so that decay-heat removal is still secured. In the second case a temperature increase occurs similar to the loss of forced cooling as the target wheel remains filled with water too. Whether in this case emergency cooling must be provided for lastly depends upon whether or not the temperature maximum remains below the melting temperature without emergency cooling. One of the suitable measures for emergency cooling would be flooding of the cavern and heat transfer via the cavern liner to the target block. The loss of cooling during handling of the target wheel does not present a problem as 5 days after shut-down handling will be started at the earliest and then a temperature of 600° C cannot be exeeded. (fig.7).

4.4 Decrease of target wheel speed.

If the target wheel speed decreases below the fixed limit (0,5 s^{-1} - 20 %) the proton beam will be stopped automatically by the normal shut down system within a second. Since even in the case of a pressure loss in the turbine and bearing circuit several seconds are needed for slowing down the wheel the shut down time of about one second is sufficient to prevent temperature rises in the target pins which might lead to destruction by melting of the (Al) cladding material. At a speed of 0,4 s^{-1} only a small part of the area (4 cm Ø see /1/) at the wheel circumference will be hit by two proton pulses and heated up to about 280°C.

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